Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

PUBLICATIONS
OF THE
Astronomical Society of the Pacific.

VOL. XXII. SAN FRANCISCO, CALIFORNIA, APRIL, 1910 No. 131

A STUDY OF SPECTROSCOPIC BINARY STARS.[1]

(Abstract of retiring President's Address, delivered at the annual meeting of the Astronomical Society of the Pacific, on the evening of March 26, 1910.)

BY W. W. CAMPBELL.

The number of known spectroscopic binary stars increased from 136 on January 1, 1905, the epoch of the First Catalogue of Spectroscopic Binaries, up to 303 on January 1, 1910. The number of fairly well-determined orbits increased in the same period from fewer than twenty to about seventy. To meet the pressing needs of observers and computers, but more especially to furnish an improved basis for the general study of binary stars, I have prepared the manuscript for a Second Catalogue of Spectroscopic Binary Stars, which will be issued in the course of a few weeks. It aims to list all binary systems discovered by means of the spectrograph at this and other observatories prior to the epoch January 1, 1910, and to include the principal facts concerning these systems available on March 15, 1910. These facts refer to the periods of revolution in the orbits, the eccentricities of the orbits, the magnitudes of the orbits, the relations concerning the masses of the bodies involved, etc.

During the preparation of the tables for publication, a study was made of those binary systems for which periods and other elements of the orbit have been determined, considering them from various points of view.

---

[1] The results of this study of spectroscopic binary stars, as outlined in the present abstract, were presented in the Silliman Lectures, delivered in Yale University, January 24 to February 2, 1910, by Director W. W. CAMPBELL.

It should be explained, by way of preface, that Harvard College Observatory formulated several years ago a most useful system of classification for stellar spectra, in which the types corresponding to advancing stages of development are represented by the capital letters Q, O, B, A, F, G, K, and M; Q and O representing the earliest types of stellar life, and M the oldest types. Gradations within the types are described by means of steps expressed in numerals or lower-case letters. For example, a star representing a stellar state midway between B and A is denoted by B5. This Harvard classification has been utilized in the present and other studies with advantage.

TABLE I.—SPECTROSCOPIC BINARIES, *O* AND *B* TYPES.

H. R.	Star	Types	Period	e	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
779	δ *Ceti*	B2	short						
1088	$\tau_{5.}$ *Eridani*	B8	short						
1347	υ_4 *Eridani*	B9	short						
2781	29 *Can. Maj.*	Oe	short						
4118	δ *Antliæ*	B9	short						
4662	γ *Corvi*	B8	short						
6027	ν *Scorpii*	B3	short						
7248	Υ *Aquilæ*	B8	short						
			d						
8238	β *Cephei*	B1	0.19	small	45,000	0.0001			
2294	β *Can. Maj.*	B1	0.25	0.1±	33,500	0.00002			
1567	π_5 *Orionis*	B3	0.87						
3129	ν *Puppis*	B1p	1.45	(0.)	6,100,000		17.1	17.1	
6247	μ *Scorpii*	B3p	1.45		4,586,000		7.2	7.2	
5944	π *Scorpii*	B2p	1.57						
6431	u *Herculis*	B3	2.05	0.05	2,800,000	0.205	6.8	2.6	0.39
6431_1	“		2.05	“	7,120,000	3.43			
1811	ψ *Orionis*	B2	2.53	0.06	4,995,100	0.780	5.53	4.19	0.76
1811_1	“		2.53	“	6,570,000	0.343			
8523	2 *Lacertæ*	B5	2.62	0.02	2,890,000	0.141	0.87	0.71	0.82
8523_1	“		2.62	“	3,550,000	0.026			
8001	57 *Cygni*	B3	2.85						0.96
936	*Algol*	B8	2.87	0.04	1,600,000	0.200	0.44	0.22	0.5
1239	λ *Tauri*	B3	3.95	0.	3,300,000	0.089			
5056	α *Virginis*	B2	4.01	0.10	6,930,000	0.833	9.6	5.8	
5056_1	“		4.01	“	11,400,000	3.68			
226	ν *Androm.*	B3	4.28	0.	4,299,000	0.173			
1131	*o Persei*	B1	4.42	0.	7,100,000	0.578			
6527	λ *Scorpii*	B2	5.6						
1852	δ *Orionis*	B	5.73	0.10	7,906,600	0.601			
8926	BD+57.2748	B3	6.07						
1542	9 *Camelopard.*	B	6.33						

TABLE I.—SPECTROSCOPIC BINARIES, *O* AND *B* .TYPES—*Continued.*

H. R.	Star	Types	Period d	*e*.	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
3623	*κ Cancri*	B8	6.39	0.15	5,890,000	0.200			
3659	*α Carinæ*	B3	6.74	0.18	1,960,000	0.007			
5984	*β Scorpii*	B1	6.9						
1788	*η Orionis*	B1	7.99	0.02	15,901,000	2.51	11.2	10.6	0.95
1788_1	"		7.99	"	16,750,000	2.15			
5231	*ξ Centauri*	B2p	8.02						
1552	π_4 *Orionis*	B3	9.52	0.03	3,393,000	0.017			
7790	*α Pavonis*	B3	11.75	0.01	1,170,000	0.0005			
7106	*β Lyræ*	B2p	12.91	0.07	33,000,000	9.7	9.6	20.9	2.2
7106_1	"		12.91	"	15,800,000	1.0			
1713	*β Orionis*	B8p	21.90	0.30	1,108,900	0.0001			
2653	o_2 *Can. Maj.*	B5p	24.3±	0.	1,670,000±	0.0003±			
1952	BD — 1.1004	B3	27.16	0.76	22,380,000	0.607			
1899	*ι Orionis*	Oe5	29.14	0.75	28,907,000	1.14			
6084	*σ Scorpii*	B1	30.±						
5190	*ν Centauri*	B2	31.±						
3734	*κ Velorum*	B3	116.65	0.19	73,200,000	1.15			
496	*φ Persei*	Bp	126.5	0.43	42,298,000	0.189			
2159	*ν Orionis*	B2	131.4						
1910	*ζ Tauri*	B3	138.	0.18	27,900,000	0.046			
154	*π Androm.*	B3	143.72	0.58	76,790,000	0.876			
6812	*μ Sagittarii*	B8p	180.2	0.44	143,500,000	3.63			
936_1	*Algol*	B8	y 1.90	0.0	89,000,000	0.060			

The first table lists the spectroscopic binaries of O and B types,—stars effectively young in age,—whose periods of revolution have been fairly well determined, arranged in the order of their periods. The first column gives the serial number in the Harvard Revised Photometry.[1] Except in the case of the last star on the list, which refers to the orbit of the center of mass of the binary system of *Algol* around the center of mass of itself and a suspected third body, the periods are all under one-half year, and two thirds of them are under ten days in length. An inspection of column "*e*," which lists the corresponding eccentricities, shows convincingly that the eccentricities are small for the shorter periods and relatively large for the longer periods; that is, the orbits are more nearly circular for the short-period binaries than for those whose periods are relatively long. The second column from the last quotes the mass of the brighter member of each system, multiplied by the cube ($\sin_3 i$) of the sine of the inclination of its orbit, in terms of the Sun's mass as unit, for which the velocities of the *two members* of the system have been observed spectrographically. The next to the last column quotes similarly the mass of the fainter member of the system. The last column contains the ratio of the mass of the fainter member to that of the brighter member. It is characteristic of orbits, as determined by means of the spectrograph, that the inclination of the orbit plane to the line of sight cannot be determined. It will be seen that the masses of the two bodies, even after they are multiplied by the sine-cube of the inclination, are, on the whole, greater than the mass of the Sun. Attention is also called to the fact that in the case of *Beta Lyræ* alone is the brighter member of smaller mass than the fainter.

---

[1] *H. C. O. Annals,* Vol. L.

TABLE II.—SPECTROSCOPIC BINARIES, *A* TYPES.

H. R.	Star	Types	Period	e	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
104	BD + 43.92	A2	short						
897	θ_1 *Eridani*	A2	short						
1380	64 *Tauri*	A2	short						
5971	Z *Cor. Bor.*	A	short						
			d						
2124	μ *Orionis*	A2	0.77						
815	RZ *Cassiop.*	A	1.20		1,170,000	0.046±	0.646	0.356	0.55
1497	τ *Tauri*	A	1.50	0.08	916,130	0.0136			
5586	δ *Libræ*	A	2.33	0.05	2,450,000	0.110	0.84	0.61	0.70
-	U *Cephei*	A	2.49						
2890	α_1 *Gemin.*	A	2.93	0.01	1,279,000	0.0097			
7326	U *Sagittæ*	A	3.38						
1568	7 *Camelopard.*	A2	3.88						
2088	β *Arigæ*	Ap	3.96	0.00	6,000,000		2.16	2.16	1.0
6324	ϵ *Herculis*	A	4.02	0.07	3,000,000	0.067			
6324_1	"		4.02	"	4,286,000	0.194			
2891	α_2 *Gemin.*	A	9.22	0.50	1,485,000	0.0015			
4072	BD + 66.664	A	11.6	large					
7710	θ *Aquilæ*	A	17.11	0.69	7,665,000	0.061	0.311	0.276	0.89
7710_1	"		17.11	"	8,610,000	0.087			
5793	α *Cor. Bor.*	A	17.36	0.33	7,600,000	0.059			
5054	ζ *Urs. Maj.*	Ap	20.54	0.50	17,500,000		2.0	2.0	1.0
8178	β *Equulei*	A	22.7±						
4295	β *Urs. Maj.*	A	27.16	0.79	1,774,000	0.0003			
622	β *Triang.*	A5	37.0±						
5291	α *Draconis*	A	51.38	0.40	30,000,000	0.42			
4689	η *Virginis*	A	71.9	0.33	25,500,000	0.126			
15	α *Androm.*	A	96.7	0.51	33,000,000	0.155			
553	β *Arietis*	A5	107.0	0.88	22,880,000	0.042	0.17	0.17	1.0

TABLE II.—SPECTROSCOPIC BINARIES, *A* TYPES—*Continued.*

H. R.	Star	Types	Period	e	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
			y						
2421	*γ Gemin.*	A	3.5±	large					
2491	*Sirius*	A	49.4	0.59					

Table II records corresponding facts for the A-type stars; that is, those which are believed to be somewhat further along in their process of development. The last star on the list, *Sirius,* it is well known, was discovered to be a visual binary in 1862. It is included in the list, technically, for the reason that the spectrograph has measured the velocity of the bright star in the system and found it to be variable, corresponding with the well-known visual orbit. In this list again the eccentricity is seen to be, in general, a function of the period of revolution. Short periods have small eccentricities, implying orbits nearly circular. The ratio of the masses is again equal to or smaller than unity.

TABLE III.—SPECTROSCOPIC BINARIES, *F* TYPES

(Cepheid variables not included.)

H. R.	Star	Types	Period	e	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
			d						
2788	R. *Can. Maj.*	F	1.14						
142	13 *Ceti*	F	2.08	0.06	981,000	0.0087			
5986	*θ Draconis*	F8	3.07	0.01	990,000	0.0041			
424	*α Urs. Min.*	F8	3.97	0.13	164,500	0.00001			
	Z *Herculis*	F	3.99						
7056	*ζ Lyræ*	F	4.30	0.00	3,030,000	0.060			
6596	*ω Draconis*	F5	5.28	0.01	2,632,000	0.0261			
8315	*κ Pegasi*	F5	6.±						
8430	*ι Pegasi*	F5	10.21	0.01	6,740,000	0.117			
3852	*o Leonis*	F5p	14.50	0.02	10,775,000	0.238	1.302	1.116	0.86
3852_1	"		14.50	"	12,571,000	0.378			
2693	*δ Can. Maj.*	F8p	275.±	0.0	5,650,000	0.0001			
6927	X *Draconis*	F8	281.8	0.42	63,000,000	0.126			
			y						
8123	*δ Equulei*	F5	5.7	0.36					
424_1	*α Urs. Min.*	F8	11.9	0.35	166,800,000	0.0098			
3185	*ι Argus*	F5	long						

In Table III we have F-type stars, representing a still older stage. Again, the short periods have orbits of small eccentricity, and the long periods, of great eccentricity.

TABLE IV.—SPECTROSCOPIC BINARIES, TYPES *G* TO *M* INCLUSIVE.

(Cepheid variables not included.)

H. R.	Star	Types	Period d	e	$a \sin i$	$\frac{m^3_1 \sin^3 i}{(m+m_1)^2}$	$m \sin^3 i$	$m_1 \sin^3 i$	$m_1 : m$
8961	λ *Androm.*	K	20.54	0.11	1,900,000	0.0006			
1708	*Capella*	G	104.02	0.02	36,847,900	0.184	1.19	0.94	0.79
1708_1	"		104.02		46,430,000	0.369			
429	γ *Phœnic.*	K5	190.±						
6148	β *Herculis*	K	410.58	0.55	60,280,000	0.052			
5235	η *Bootis*	G	489.14	0.18	56,010,000	0.0293			
			y						
4375	ξ *Urs. Maj.*	G	1.8						
8650	η *Pegasi*	G	2.24	0.16	157,800,000	0.234			
7776	β *Capric.*	G	3.77	0.44	377,000,000	1.13			
6134	α *Scorpii*	Map	5.8	0.20	60,490,000	0.0020			
6752	70 *Ophiuchi*	K	87.86	0.50					
99	α *Phœn.*	K	long						
539	ζ *Persei*	K	long						
549	ξ *Piscium*	K	long						
854	τ *Persei*	Gp	long						
915	γ *Persei*	Gp	long						
1066	f *Tauri*	K	long						
2216	η *Gemini*	Ma	long						
2296	δ *Colum.*	G5	long						
2553	τ *Puppis*	K	long						
2854	γ *Can. Min.*	K	long						
4301	α *Urs. Maj.*	K	long						
8079	ξ *Cygni*	K5	long						
8115	ζ *Cygni*	K	long						

Table IV lists the G and M binary types for which orbital data are available. It will be recalled from the preceding illustrations that about two thirds of the O and B types listed have periods of less than ten days; that half the A types have periods of less than ten days; that half the F types have periods of less than ten days; and it is interesting to note that there are no known binaries of G-M types whose periods are less than twenty days. The eccentricities in column *"e"* are again seen to be functions in general, of the length of period.

TABLE V.—SPECTROSCOPIC BINARIES—SPECTRAL TYPES, PERIODS, AND ECCENTRICITIES.

	"short"	0^d — 5^d	5^d — 10^d	10^d +	Years "long"
O and B types...	8	15	10	14	1
Period	short	$2^d.4$	$6^d.9$	$73^d.2$	$1^y.9$
Eccentricity		(10) 0 .04	(5) 0 .10	(11) 0 .34	(1) 0 .0

TABLE V.—SPECTROSCOPIC BINARIES—SPECTRAL TYPES, PERIODS, AND ECCENTRICITIES —*Continued.*

	"short"	0^{d} — 5^{d}	5^{d} — 10^{d}	10^{d} +	Years	"long"
A types	4	10	1	11	2	
Period	short	$2^{d}.65$	$9^{d}.2$	$43^{d}.7$	$26^{y}.45$	
Eccentricity		(5) 0 .04	(1) 0 .50	(8) 0 .55	(1) 0 .59	
F types	0	6	2	4	2	1
Period		$3^{d}.1$	$5^{d}.6$	$145^{d}.1$	$8^{y}.8$	long
Eccentricity		(4) 0 .05	(1) 0 .01	(4) 0 .11	(2) 0 .36	
G to M types	0	0	0	3	7	13
Period				$104^{d}.85$	$16^{y}.3$	long
Eccentricity				(2) 0 .06	(6) 0 .34	
Total	12	31	13	32	12	14
Mean period		$2.^{d}59$	$6^{d}.91$	$75^{d}.0$	$15^{y}.53$	
Mean eccentricity		(19) 0 .05	(7) 0 .14	(25) 0 .35	(10) 0 .33	

The relations existing between the spectral types, lengths of period, and eccentricities are presented in a more condensed form in Table V. The table is double entry, with the lengths of period classified in the first line, and the types, average periods, and average eccentricities in the following twelve lines. It will be noted that there is a relation between average periods and average eccentricities; the eccentricity increases in value with the increase of period. The decrease in the number of short-period binary systems, with advancing stellar age, is graphically evident from the zero in the F division and the three zeros in the G-M division. The facts referred to are brought out even more forcibly in the last three lines of the table. The second line from the last, "total," sums up the number of binaries in all the four types. The next to the last line gives the average periods of these binary systems. The last line gives the average eccentricities of all those stars in these divisions for which the eccentricities have been determined, the number of eccentricity values in each case being indicated by the numbers in parentheses. Thus there are thirty-one binaries whose definitely determined periods, lying between zero days and five days, average 2.59 days in length. For nineteen of these the eccentricities have been determined, and the average value is 0.05. The close relationship existing between length of period and eccentricity of orbit is so apparent that we need not further study the tabulations.

The period of revolution is a function of the spectral type, and the eccentricity is a function of the period. What is the significance of these facts? Let us recall that DARWIN and POINCARÉ studied the origin of binary stars from theoretical considerations, and came to the conclusion that a condensing nebulous mass, rotating on its axis constantly faster and faster, to keep pace with loss of heat through radiation, should eventually separate into two nebulous masses revolving around their mutual center of mass. These two masses would, in the beginning, be revolving in contact in an orbit essentially circular. With advancing time, tidal disturbances should cause the two bodies to draw apart rapidly at first, and less rapidly later.

In the spectroscopic binary systems described in this address have we not a tolerably complete sequence of orbits illustrative and confirmatory of the DARWIN-POINCARÉ hypothesis? The short-period orbits should be circular or nearly so, and should appertain to stars of early spectral types; the longer periods should, in general, attach to the more eccentric orbits and the older spectral types; and these are the facts established by actual observation of binary systems. There are many lines of supporting and confirmatory evidence. Let us consider a few from the *Algol* variable stars. Many of the *Algols* have been observed photometrically with great accuracy, by ROBERTS and others, and certain characteristics of these systems have been deduced from a study of their light curves. Only two *Algol* stars have had their orbits determined from a satisfactory series of spectrographic velocity measurements. The main

TABLE VI.—VARIABLES OF ALGOL TYPE.

No. of stars.	Periods in days.	No. of stars.	Periods in days.	No. of stars.	Periods in days.
9	0 to 1	1	7 " 8	1	31
11	1 " 2	1	8 " 9	1	32
17	2 " 3	2	9 " 10	1	35
12	3 " 4	0	10	1	262
4	4 " 5	0	11	——	
4	5 " 6	2	12	72	
4	6 " 7	1	13		

5 stars *B* type spectrum.
13 " *A* " "
2 " early *F* type spectrum.
Others unknown spectrum.

2 spectroscopic orbits,—

$e = .03$	$P = 2^d.87$
$e = .05$	$= 2.33$
Means, .04	2.6

Several photometric orbits, all nearly circular; short periods.

TABLE VI.—VARIABLES OF ALGOL TYPE—*Continued.*

DENSITIES.

	No. of stars.	Average density.
ROBERTS	4	0.13 $\odot$
RUSSELL	17	.20 $\odot$
RISTENPART	10	.07 $\odot$

facts concerning these systems are referred to in Table VI. Seventy-two *Algol* stars are known, not counting a considerable number of suspects. The numbers having periods of certain lengths are tabulated in columns 1 and 2. There are nine whose periods are less than one day; forty-nine whose periods are less than four days; twelve whose periods are between four and seven days; and only eleven of periods longer than seven days. The greater number of *Algols* are so faint that their spectral types have not been determined by Harvard College Observatory or elsewhere. Of those whose types are known, five stars are of B type, thirteen of A type, and two of early F type. None have been recognized as of late F, or of G-M types. The eccentricities and periods of the two spectrographically determined orbits have the mean values—

$$e = 0.04$$
$$P = 2.6 \text{ days}$$

Of the several photometric orbits determined the eccentricity is thought to be very small, with two or three exceptions. ROBERTS, RUSSELL, and RISTENPART have investigated the average density of four, seventeen, and ten *Algol* stars, respectively, with the results, as quoted, that the average densities are less than one fifth that of the Sun's density. From the clews which we have here and there as to the masses of *Algol* stars, we can have no reasonable doubt that they are in general attenuated bodies, with diameters greatly exceeding the Sun's diameter.

Considering all these facts, it is easy to arrive at an apparently extremely important conclusion as to why we have more than a few *Algol* variables.

The two members of an *Algol* system are in general so near each other and so large in diameter that eclipses occur with great ease: they are observable by those of us who are not situated exactly in the plane of the orbit; the eclipses last a long time, so that even the unsystematic observations of the past have readily detected variable brightness. As the two members of a system grow further and further apart, corresponding to the longer periods as tabulated in column 2, the number of eclipsing pairs decreases very rapidly, as indicated in column 1. *Algol* stars of types G-M appear not to have been observed for the reasons that the binary stars of these types have their components relatively far apart; and eclipses would be of relatively short duration both because the stars are widely separated and because they are of smaller diameter, being more condensed. The observer would have to be situated very closely in the plane of the orbit in order to witness an eclipse, and his chances for observing an eclipse would be small, as compared with eclipses of close systems.

Closely related to the *Algols* are the β *Lyræ* variables. These appear to be in fact an extreme type of *Algol* star, whose two component stars are highly attenuated and revolving nearly or quite in contact. Their spectra are of early types, and their orbits are circular or nearly so, in so far as they have been investigated.

TABLE VII.—VISUAL DOUBLE STARS.

Star.	Period. y	*e*	Spectrum.
δ *Equulei*	5.70	0.36	F5
13 *Ceti*	7.42	0.74	F
κ *Pegasi*	11.37	0.40	F5
ε *Hydræ*	15.70	0.68	F8
β 883	16.35	0.48	
ζ *Sagittarii*	21.17	0.18	A$_2$
β 612	22.8	0.48	A
9 *Argus*	23.3	0.68	F8
82 *Ceti*	24.00	0.15	K
42 *Comæ*	25.56	0.46	F5
	17.33	0.461	

Star.	Period. y	*e*	Spectrum.
85 *Pegasi*	25.70	0.43	G
β *Delphini*	27.66	0.36	F5
Σ 3121	34.00	0.33	
ζ *Herculis*	34.53	0.46	G
20 *Persei*	36.00	0.75	F
β 581	41.2	0.53	
η *Cor. Bor.*	41.51	0.28	G
ξ *Scorpii*	44.5	0.77	F8
μ *Herculis*	45.39	0.21	
β 416	45.90	0.62	K5
	37.64	0.474	

TABLE VII.—VISUAL DOUBLE STARS—*Continued.*

Star.	Period. y	*e*	Spectrum.
Σ 2173	46.0	0.20	G
Sirius	49.4	0.59	A*
*o*Σ 298	52.0	0.58	
β 513	53.0	0.35	A_2
γ *Andr.* BC	55.0	0.82	**
τ *Cygni*	53.0±	0.31±	F
ζ *Cancri*	59.1	0.38	F
ξ *Urs. Maj.*	59.8	0.41	G
99 *Herculis*	64.5	0.81	F8
*o*Σ 235	66.0	0.50	F
	55.8	0.495	

Star.	Period. y	*e*	Spectrum.
8 *Sextantis*	68.8	0.60	A_2
γ *Cor. Bor.*	73.0	0.48	A
*o*Σ 234	77.0	0.30	
*o*Σ 400	81.0	0.46	
α *Centauri*	81.2	0.53	G, K_5
γ *Centauri*	88.0	0.80	A
70 *Ophiuchi*	88.4	0.50	K
*o*Σ 387	90.0	0.60	
*o*Σ 285	97.9	0.60	
φ *Urs. Maj.*	99.7	0.44	A_2
	84.4	0.531	

Star.	Period. y	*e*	Spectrum.
Σ 3062	104.6	0.45	F
ω *Leonis*	116.2	0.54	G
Σ 228	123.1	0.31	
ξ *Bootis*	148.5	0.54	K5p
γ *Cor. Aus.*	152.7	0.42	F8
Σ 2	166.2	0.40	A
O_2 *Eridani* BC	180.0	0.13	***
25 *Cam. Ven.*	184.0	0.75	F
Σ 2107	186.2	0.39	
γ *Virginis*	194.0	0.90	F
	155.6	0.483	

Let us examine Table VII, giving data for fairly well-determined orbits of visual double stars. Here is a list of fifty stars, in groups of ten. The periods, eccentricities, and spectral types as far as known are quoted for the individual star, and the means by tens are given for the periods and eccentricities. It will be noted that in these widely separated systems there is not a single O or B type, representing the early stages of binary existence. There are a few A types, but the major number are of the advanced F type and G and K types. I suspect the K, M, and N types are not more fully represented for the reason that in these old-age systems the two components are in general so far apart that the periods of revolution are many hundreds or thousands of years. It will be recalled that double-star observations made since the day of Sir WILLIAM HERSCHEL enable us to determine satisfactorily the orbits of short-period double stars only. In fact, the longest period in the present list of fifty is 194 years. In this connection I am pleased to refer to the work of Professor SEE, in the early 1890's, on the evolution of stellar systems, wherein he calls attention to the high eccentricities of visual double-star orbits, and elaborates the theory that the visual binary systems have been evolved, with increasing periods and eccentricities, through the action of tidal friction. In this table, arranged in the order of length of periods, there is some evidence of progression in the value of the eccentricity, but this is not very definite. These eccentricities of visual orbits, varying from 0.43 to 0.54, are, however, appreciably larger than the average eccentricity, 0.34, of the thirty-five spectroscopic binary systems of longest period. To repeat, the spectroscopic binaries with periods between zero and five days have eccentricity 0.05; those with periods between five and ten days, eccentricity 0.14; those with periods between ten days and a year, 0.35; those with periods between one year and eighty-eight years,—average, 15½ years,—eccentricity 0.33; and fifty visual double-star orbits, with periods between five and 194 years,—average, seventy-two years,—have average eccentricity 0.49.

---

* Star A = — 1.5, F type.
Star B = 9, yellow.

** Star A = 2.28, K type.
Star BC = 5.08, blue.

*** Star A = 4.5, G5.
Star BC = 9, blue.

There are many other equally interesting considerations attaching to this subject, but time forbids presenting more than one. A paper of considerable length on the subject is ready for publication in the *Lick Observatory Bulletin.*

The remaining consideration relates to the question of masses in binary systems. Except in the case of *Algol* stars, and here only on the assumption that we are in the plane of the orbit, it is not possible to determine from spectrographic observations alone the masses in binary systems. The cube of the sine of the unknown inclination of the orbit to the line of sight is involved. However, it can be shown that in a very great number of such systems the average value of i would be 57°.3 and of $\sin^3 i$ 0.59. If we insert in the tables this value of $\sin^3 i$, in the seventeen cases for which we have been able to determine the values of $m \sin^3 i$ and $m_1 \sin^3 i$ (that is, the systems in which both spectra are visible and have been measured), we find that the masses of the components in the majority of cases are much greater than the Sun's mass. Further, the masses, on the whole, are not very unequal. For those having unequal masses, the fainter component has the smaller mass, except in the one case of *Beta Lyræ*. In this one case the masses are so unequal and the two components are so close together that it is not impossible, as MEYERS has suggested, the actual relative intensity of the two bodies is reversed by an absorbing medium which completely encloses the binary system and which, owing to the greater attractive power of the more massive component, is more condensed around that component.

In connection with these facts let us consider three others.

Sixty-three of the binary systems contained in the Catalogue of 303 systems show more or less clearly the existence of two spectra in each. Of these sixty-three, thirty-one are of O and B types, twenty-three of A type, five of F type, three of G type, one of K type, and none of M type: a clear and decided preference for the early types. In each one of these cases, in which one spectrum is weaker than the other, the weaker spectrum refers to the less massive body, so far as measurements are available, except in the case of *Beta Lyræ*.

Harvard College Observatory has catalogued forty-one stars whose spectra are composite,—that is, each spectrum is the sum of two spectra. It has not been possible to classify the fainter spectrum in all cases, but of those completely described the fainter spectrum is of an earlier type than the brighter spectrum, with, I believe, seven or eight exceptions; and in two of these the spectral types differ but slightly.

It is characteristic of the well-known visual double stars of unequal magnitude that the fainter component is bluer than the brighter component; that is, the fainter component has the earlier type of spectrum. There appear to be a few exceptions to this rule.

All these facts appear to be in harmony with the following hypothesis: The nebula which gives rise to a binary system, through fission, divides into two masses, usually not very unequal, and the spectra at first are substantially of the same type. Because the masses are nearly equal, the chances for observing both spectra are favorable. In general, the more massive component increases in brilliancy and lives its life more rapidly than the component only slightly less massive. As Sir WILLIAM HUGGINS suggested rather casually many years ago, this may be due to the influence of the greater internal gravitational power of the more massive star. Materials are drawn more powerfully toward the center of this star, and in consequence heat and light are generated and radiated more rapidly. With advancing time, the fainter component, living its life less rapidly, is lost in the rays of the more luminous primary, until such time as the separation of the components enables them to be observed as a visual double star, with the less developed secondary several visual magnitudes fainter than the more massive primary.

We can all recall a few exceptions, which apparently contradict this hypothesis. For example, the faint companion of *Sirius,* having less than half the mass of the primary, is said to be of spectral type further advanced than that of the primary. It should also be stated that LEWIS, of Greenwich, discussing meridian circle and micrometer observations of certain prominent double stars, has deduced a greater mass for the fainter companion than for the more brilliant yellow primary, in nearly all cases investigated. Professor BOSS has informed me, however, that his investigations of double stars of this class reverse LEWIS's conclusions, and that the blue companions in double stars are in reality either equal to or less massive than their primaries of older spectral type.

The spectrographic observations at the Yerkes Observatory have established that one star in three, certainly, of the very early-type spectra, is a spectroscopic binary. The Lick Observatory observations have been confined more largely to the middle and later stellar types, with the result that one star in six, more or less, is proved to be a spectroscopic binary. These different ratios seem to be due to the fact that the early types are of short periods, which makes their discovery easier and more prompt. They likewise are characterized by a higher range of velocity variations. The spectroscopic binaries of older types revolve in larger orbits with longer periods, and change their velocities more slowly. They are on these accounts more difficult to discover. Binaries of the early types may or may not actually be more numerous than those of the later types. AITKEN's double-star investigations have shown that one star, on the average, out of every eighteen is a visual binary. As explained in AITKEN's paper,[1] the close binary systems are more numerous than those whose components are further and further apart. AITKEN has also found that a larger proportion of bright stars are double than is the case for fainter stars. With an infinity of time for the evolutionary processes involved, it seems difficult to explain the greater scarcity of wide pairs. But this is a fact which presumably has great significance. My radial velocity studies of the stars seem to indicate that the stars of different magnitudes are mixed much more thoroughly in space than has heretofore been supposed. It seems, therefore, quite probable, in the absence of accurate parallax data, that the fainter double-star systems are actually closer to us, on the average, than the earlier investigations have led us to believe. It seems reasonable also that large parent nebulæ should divide into two components more freely than small nebulæ do.

Tables III and IV do not include the *Cepheid-Geminid* variables, for the reason that these mysterious systems seem to be in a class by themselves, so far as our present knowledge goes.

TABLE VIII.—CEPHEID-GEMINID VARIABLES.

No. of stars.	Period in days.	No. of stars.	Period in days.	No. of stars.	Period in days.
7	0-1	1	8-9	1	27
0	1-2	3	9-10	1	35
1	2-3	1	10	1	38
5	3-4	2	12	1	39
5	4-5	1	14	1	41
5	5-6	1	16	—	
5	6-7	2	17	53	
8	7-8	1	20		

---

[1] *Lick Observatory Bulletin*, **6**, 1, 1910.

TABLE VIII.—CEPHEID-GEMINID VARIABLES—*Continued.*

11 orbits computed.

$P^{11} = 7^d.3$

$e_{11} = 0.31$

Spectrum	O-B	A	F	G-K5	M	Unknown
No.	0	1	14	26	0	12
Average period		$0^d.6$	$8^d.2$	$11^d.4$		$7^d.9$

Table VIII refers to fifty-three variables of this class, with periods distributed as in the second column. To seven are assigned periods less than one day. I suspect that some of these extremely short period variables may, in fact, later be assigned to the cluster type of variables; or it is not impossible that the cluster-type variables are entitled to classification with the *Cepheid* variables. None of the many hundreds of cluster-type variables discovered by Harvard College Observatory have yet been submitted to radial velocity measurements, owing to their faintness. There are twenty-eight of the *Cepheid-Geminid* variables with periods between two and eight days. Spectrographic orbits have been computed for eleven members of this class, with average periods of 7.3 days and eccentricity 0.31. The numbers and periods corresponding to the different spectral types are quoted in the table. There are none of the Q, O, B, or M type, so far as known. There is only one A type; and there are thirty-nine advanced F type and G type. The length of period seems to increase slowly with the spectral type, but the relationship is not strongly marked.

TABLE IX.—CEPHEID-GEMINID VARIABLES.

H. R.	Star	Types	Period d	e	$a \sin i$	$\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$	$\text{Min}_v-\text{Max}_1$ d	$\text{Max}_v-\text{Min}_1$ d
2332	RT *Aurigæ*	G	3.73	0.37	856,500	0.0018	+ 0.2	+ 0.4
7518	SU *Cygni*	F5	3.84	0.21 ±	1,350,000 ±	0.0058 ±	+ 0.2 ±	+ 0.0 ±
7988	T *Vulpec.*	F -	4.44	0.43	969,180	0.0018	+ 0.3	+ 0.1
8571	δ *Cephei*	G	5.37	0.36	1,371,000	0.0037		
6863	Y *Sagittarii*	G	5.77	0.16	1,485,000	0.0040	+ 0.78	+ 0.1 ±
6616	X *Sagittarii*	F8	7.01	0.40	1,334,000	0.0016	— 0.2 ±	— 1.3 ±
7402	U *Aquilæ*	G	7.02				— 0.5	
7570	η *Aquilæ*	G	7.18	0.49	1,773,000	0.0043	0.0 ±	— 0.6
6742	W *Sagittarii*	F5	7.60	0.32	1,930,000	0.0050	— 0.1	+ 0.2
7609	S *Sagittæ*	G	8.38	0.35 ±	2,000,000 ±	0.0049 ±	— 0.2 ±	+ 0.4 ±
7107	κ *Pavonis*	F5	9.09					
2650	ζ *Gemin.*	G	10.15	0.22	1,797,800	0.0023	— 0.2	— 0.3
7932	X *Cygni*	F5p	16.39					
6661	Y *Ophiuchi*	G	17.12	0.10	1,999,000	0.0011	— 1.3	+ 0.5 ±
2310	T *Monocer.*	G	27.01					
3884	l *Carinæ*	G	35.53				— 2½ ±	

Table IX contains the principal orbital elements, so far as known, for sixteen stars of this class, arranged in the order of their periods. A most peculiar discovery concerning these systems, as described in the last two columns of the table, was made by ALBRECHT several years ago: each star has its maximum brightness at or near the time of most rapid approach *toward the observer,* and its minimum at or near the time when receding most rapidly *from the observer.* Orbits of enough stars in this class have been investigated to guarantee, beyond reasonable doubt, the conclusion that the time of maximum in each of the systems is a function of the observer's position in space. Many theories to account for this strange phenomenon have been advanced and discussed, only to be found wholly or largely unsatisfactory.

Several additional conclusions can be drawn from the data. The ratios in the second column from the last indicate clearly that the masses of the companion stars are very small in proportion to the masses of their primaries. The column "$a \sin i$" declares that the primaries revolve in orbits whose dimensions may be described as minute.

It is reasonably certain that all *Cepheid-Geminid* variables, as well as *Algol* variables, are spectroscopic binary systems. The future will probably establish the fact that the cluster variables are binaries.

The importance of spectroscopic binary investigations, in their bearing upon questions of the origin and development of multiple star systems, can scarcely be overestimated.

NOTES ON SOLAR MAGNETIC FIELDS AND RELATED PHENOMENA.

By GEORGE E. HALE.

CLASSIFICATION OF SUN-SPOT LINES.

A study of the Zeeman effect in the spectra of sun-spots has made it necessary to formulate a system of classification of the numerous types of lines observed under various conditions. Before the present work was undertaken, spot spectra were known to include band lines, belonging to the flutings of such compounds as titanium oxide, magnesium hydride,